Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 96 (2013) 2300 – 2309

Procedia
Social and Behavioral Sciences

13th COTA International Conference of Transportation Professionals (CICTP 2013)

Study on Influencing Factors for Service Performance of Anti-sliding Layer with Hot Melting Macadam

Yixiang Cao, Junyan Yi, Zhaojie Sun, Decheng Feng

School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin, 150090, China

Abstract

This paper presents a new treatment to icy road, anti-sliding layer with hot melting macadam. Experiments were done to investigate the different factors influencing the effect of hot melting macadam anti-sliding layer. The friction coefficient and texture depth of anti-sliding layer were taken as the quantitative index. The icy layer thickness, macadam particle size and macadam temperature were taken as influencing factors, and the full-scale test including three factors was carried out. The BPN (British pendulum number) was measured using British pendulum test, and the status of macadam spalling was observed at the same time. The TD (texture depth) was measured by handle sand patch, the significant analysis, multiple comparison and regression analysis were used to analyze the experimental data. Experimental phenomenon and data analysis show that the three experiment factors have remarkable effect on the design indexes, and there are also prominent interactions among them; the application result of hot melt macadam anti-sliding layer is optimum when icy layer is 2cm. At last 9.5mm particle size of macadam and 90℃ temperature of macadam were recommend to use when the thickness of icy layer is 1cm~3cm.

Key words: road engineering; anti-sliding layer with hot melting macadam; experimental design; icy roads; statistical analysis;

1. Introduction

In north China region, particularly in northeast China often appear icy roads. The friction action between wheel and road surface declined rapidly on icy roads, and this can induce easily slip and traffic accidents. According to a survey, 35% of winter traffic accidents in the big and medium city were caused by icy roads. And the vehicle speed would drop by 2/3[1], which reduced the use efficiency of vehicles, increasing oil consumption quantity and use-cost. So the study of rapidly and effectively reducing the adverse impact of icy roads on traffic will have great economic efficiency in practical use and social benefits.

Now there is rich experience in icy roads treatment at home and abroad, the main treatment methods of icy roads include passive de-ice methods and initiatives de-ice methods [2].

In the passive de-ice methods, manual removal and physical ablation are inefficient and expensive [3-4]. Wang Feng et al. proposed that using magnetic energy heating system was economic and environmental, but it did not have practical application [5]. Spreading aggregate direct was widely used in Norway, but it may bring air and water pollution [6-8]. Using normal chemical agent sometimes has limited effect. Some has good effect, but also show the defects of corrosive action and environmental pollution [9-10].

In the initiative de-ice methods, there including rough riding surface, self-stress elasticity pavement and asphalt mixture with salt, these methods are still under investigation and appear to be promising [11-16].

This paper proposes a new method to treatment icy roads, hot melting macadam anti-sliding layer. The principle is that spreading heated macadam on the icy roads, and melting the ice. Macadam with melting water freezes again under the low temperature, and forms a skid resistant layer. When temperature rise, the skid resistant layer melts, and the macadam can be recycled. Macadam is steady among icy layer which can supply sufficient friction. Hot melting macadam anti-sliding layer is a

doi:10.1016/j.sbspro.2013.08.259

simple, rapid, effective and economic method which can increase the skid resistance of icy roads, which has been believed to have a broad application foreground especially in low grade highway.

Fig. 1. Hot melting macadam anti-sliding layer

2. Test scheme design

Hot melting macadam anti-sliding layer is applied mostly to improve the anti-sliding ability of icy layer for low grade highway, that is to say, the strength and friction of anti-sliding layer is two key factors of its service performance. The friction of road pavement depends on the microstructure of pavement surface, i.e. surface roughness of aggregates, which can be reflected by BPN [17]. The texture depth is also an important index of pavement roughness, always used to evaluate macro-roughness, drainage and anti-sliding performance. The status of macadam spalling can indicate the bond performance between macadam and icy surface. Therefore, in this paper, BPN, texture depth and the status of macadam spalling is taken as test index.

Considering experiment content and practical application, the experimental factors and levels just as table 1 showed.

Tab.1 Experimental factors and levels

Test level	Icy layer thickness/cm	Particle size/mm	Macadam temperature/℃
1	1	4.75	60
2	2	9.5	90
3	3	13.2	120

3. Test procedure

Cubic samples are firstly put into the iron box. Set the temperature of refrigerator at -8^{o}C and put the box into the refrigerator. Then pour water into the box and set the height of water level to specific value based on required thickness of icy pavement and volume expansion of water. The measured macadam (wet weight) are put into oven with high temperature heat and then cool the sample to required temperature. The temperature of macadam can be measured by temperature measuring probe. Level the sample and put heavy objects on the macadam to press them into the icy layer, and after that put the sample into the refrigerator until the water is frozen. Lastly take the sample out of the refrigerator, and then the texture depth (handle sand patch) and BPN (the British pendulum test) are tested. When conducting the tests, the status of macadam spalling of the sample is observed at the same time.

4. Test phenomena and results

4.1 Test phenomena

It was observed in the test that:

- 60°C macadam with three particle sizes are paved on the icy layer. There is no obvious melting water on the surface, and the macadam and icy layer freeze and bond quickly;
- When the temperature of macadam is 60°C, macadam spalling for 9.5mm and 13.2mm sizes can be observed;
- Obvious melting water can be observed when the temperature of macadam reaches 90°C;
- Excessive melting water exist when the temperature of macadam reaches 120°C.

The phenomena indicate that 60°C is too low that the macadam could not be embedded into the icy layer well. When the temperature is 120°C, excessive melting water is produced. And if this method is used, temporary traffic management should be applied until macadam bonds well with icy layer.

4.2 Test data

In this paper, total eighty-one tests, including three parallel ones for each group and containing three factors and three levels, are performed. This paper, due to space limitation, only lists the average of BPN and texture depth of different tested groups. And the results can be shown with scatter diagrams.

Tab.2 Combination mode of particle size and temperature of macadam

Combination experiment	Particle size r/mm	Macadam temperature t/℃
1	4.8	60
2	4.8	90
3	4.8	120
4	9.5	60
5	9.5	90
6	9.5	120
7	13.2	60
8	13.2	90
9	13.2	120

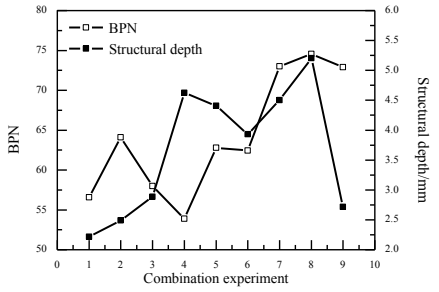

Fig.2 Average test values for 1cm icy layer

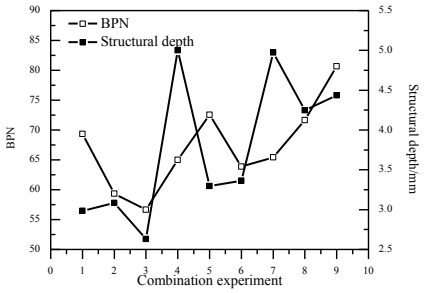

Fig.3 Average test values for 2cm ice layer

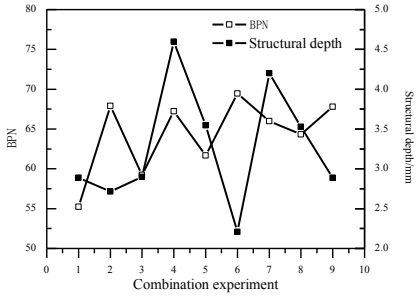

Fig.4 Average test values for 3cm ice layer

5. Statistics analysis of test data

5.1 Significance analysis results of test data

To analyze the significance of test data, iteration influences of the three factors were considered. And the analysis on the variance of three-factors duplicate test is was conducted.

From the analysis results above, it can be concluded that:

Tab.3 Significant analysis results summary

Effect	BPN	Texture depth
Very significant	Particle size	All factors
	Icy layer thickness ×Particle size	
	Icy layer thickness ×Particle size× Macadam temperature	
Significant	Icy layer thickness	——
	Macadam temperature	
	Particle size× Macadam temperature	
Not significant	Icy layer thickness ×Macadam temperature	——

5.2 LSD (least significant difference) analysis of test data

The analysis above just investigates the influence of different factors on design index. To obtain the comparison between different levels of the same factor, LSD (least significant difference) analysis can be taken:

$$LSD_a = t_{a(df_e)} S_{\bar{x}_{i.}-\bar{x}_{j.}} \quad (1)$$

Where $t_{\alpha(df_e)}$ was the critical value of f test where significance level is α. And $S_{\bar{x}_{i.}-\bar{x}_{j.}}$ was the standard deviation of the average value;

$$S_{\bar{x}_i-\bar{x}_j} = \sqrt{2MS_e / n} \quad (2)$$

Where MS_e was the mean square error of F test, and n was the replication times of each treatment. When the significance level α=0.05 or 0.01, $t_{0.05(df_e)}$ or $t_{0.01(df_e)}$ could be obtained through checking table. If $\left|\bar{x}_{i.} - \bar{x}_{j.}\right|$ was less than $LSD_{0.05}$, the relationship was not significant, no signal marked; if the value was between $LSD_{0.05}$ and $LSD_{0.01}$, the relationship was significant, mark '*' on the upright of deviation value; if the value was larger than $LSD_{0.01}$, the relationship was very significant, mark '**'.

Tab.4 Multiple comparison results of thickness of ice

Dependent variable	（I）Icy layer thickness	（J）Icy layer thickness	Average difference (I-J)	Significance
BPN	1.00	2.00	-2.9263	*
		3.00	-0.0622	
	2.00	1.00	2.9263	*
		3.00	2.8641	*
	3.00	1.00	0.0622	
		2.00	-2.8641	*
TD	1.00	2.00	-0.1152	
		3.00	0.3889	**
	2.00	1.00	0.1152	
		3.00	0.5041	**
	3.00	1.00	-0.3889	**
		2.00	-0.5041	**

It can be concluded that:

- BPN reached the maximum value when the icy layer thickness was 2cm, and it decreased when the thickness was 3cm. BPN got its minimum value when the thickness was 1cm.
- BPN value of sample with icy layer of 2cm thickness was much larger than that with icy layer of 1cm and 3cm thickness, and the difference between BPN of the samples of 1cm and 3cm icy layer thickness was not significant.
- The texture depth reached the maximum with 2cm icy layer thickness, and it decreased when the thickness was 1cm. The icy layer thickness got its minimum value when the thickness was 3cm.
- The texture depth of sample with icy layer of 3cm thickness was much less than that with icy layer of 2cm and 1cm thickness, and the difference between texture depth of the samples of 1cm and 2cm icy layer thickness was not significant.

To explain the results above, two forms of interaction between icy layer thickness and macadam can be introduced. With the increase of icy layer thickness, the embedding depth of macadam increases, which leads to the increase of bond performance between macadam and icy layer. On the other hand, with the increase of energy required to melt icy layer with the same thickness, the embedded depth of the macadam decreases. For the varying influence of these two functions and the interaction between different factors, BPN and texture depth have also a great change

Tab.5 Multiple comparison result of particle size of macadam

Dependent variable	（I）Icy layer thickness	（J）Icy layer thickness	Average difference (I-J)	Significance
BPN	4.75	9.50	-3.6167	**
		13.20	-9.9996	**
	9.50	4.75	3.6167	**
		13.20	-6.3830	**
	13.20	4.75	9.9996	**
		9.50	6.3830	**
TD	4.75	9.50	-1.1300	**
		13.20	-1.3207	**
	9.50	4.75	1.1300	**
		13.20	-0.1907	*
	13.20	4.75	1.3207	**
		9.50	0.1907	*

It can be concluded as follows:

- BPN reaches the maximum with particle size of 13.2mm, and it decreases when the particle size is 9.5mm. BPN gets its minimum value when the particle size is 4.75mm;
- BPN values of three particle sizes are all significant;
- The texture depth reaches the maximum with particle size of 13.2mm, and it decreases when the particle size is 9.5mm. The texture depth gets its minimum value when the particle size is 4.75mm;
- The texture depths of three particle sizes are all significant.

With the increase of particle size, the aggregate roughness, aggregate edges and corners and BPN all increase. At the same time, the aggregate part emerging from the ice surface increases when macadam and icy layer are frozen together, and the texture depth also increases.

Tab.6 Multiple comparison result of macadam temperature

Dependent variable	（I）Icy layer thickness	（J）Icy layer thickness	Average difference (I-J)	Significance
BPN	60.00	90.00	-3.0248	*
		120.00	-2.1470	
	90.00	60.00	3.0248	*
		120.00	0.8778	
	120.00	60.00	2.1470	
		90.00	-0.8778	
TD	60.00	90.00	0.3848	**
		120.00	0.8911	**
	90.00	60.00	-0.3848	**
		120.00	0.5063	**
	120.00	60.00	-0.8911	**
		90.00	-0.5063	**

It can be concluded from the above analysis that:

- BPN reaches the maximum with macadam temperature of 90℃, and it decreases when the temperature is 120℃. BPN gets its minimum value when the temperature is 60℃;
- BPN value of sample with macadam temperature of 90℃is significantly different from that with macadam temperature of 60℃, but the difference between BPN of other levels is not significant.
- The texture depth reaches the maximum with macadam temperature of 60℃, and it decreases when the temperature is 90℃. The texture depth gets its minimum value when the temperature is 120℃.
- The effect of three macadam temperatures on texture depth is all significant;

With the increase of temperature, the embedded depth increases, leading to the increase of strength and BPN. But if the temperature is excessively high, the volume of melting water is excessive, and this might induce the ice membrane. This will induce the decrease of aggregate angularity and BPN. In addition, with the increase of temperature, the embedded depth increases and texture depth decreases.

5.3 Regression analysis of test data

Through the above analysis of variance, the differences of significance level between tests for different factors are obtained. And the preferential orders for different levels but with the same factor are also able to be calculated. To offer better guidance of practical application, basing on the basic condition of icy layer thickness, the recommended values of macadam particle size and heating temperature can be presented. To investigate the matching nature among different icy layer thicknesses, particle sizes and macadam temperatures, multiple-factor-regression analysis should be applied.

5.3.1.Regression analysis of BPN for three kinds of ice layers

Multiple linear regression analysis was used for different thickness icy layers with particle size of macadam (x_1) and temperature of macadam (x_2) as arguments, and BPN as dependent variable (y).

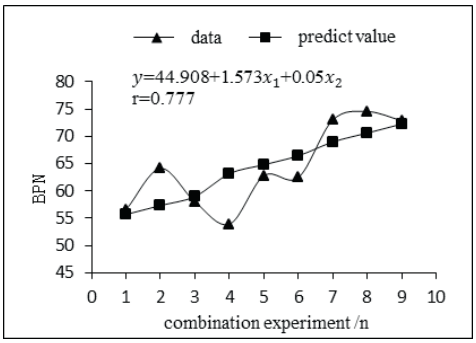

Fig.5 Regression analysis of BPN of 1cm icy layer

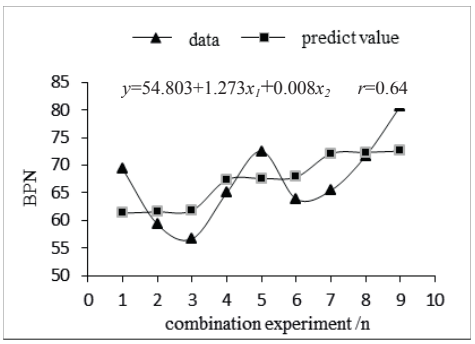

Fig.6 Regression analysis of BPN of 2cm icy layer

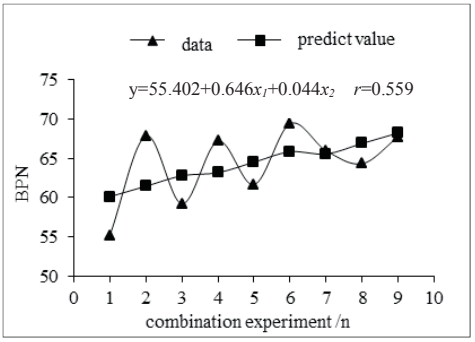

Fig.7 Regression analysis of BPN of 3cm icy layer

The r in above figure is regression coefficient. The equations are believed to be meaningful when $|r|>0.4$, so these equations are meaningful. The Figure 5 to Figure 7 show that BPN increases with the increase of particle size and temperature of macadam. The BPN is maximum with 13.2mm particle size and 120℃ macadam temperature.

5.3.2. Regression analysis of texture depth of three levels of icy layer

Multiple linear regression analysis was used for different levels of icy layer thickness with macadam particle size (x_1) and macadam temperature (x_2) as argument, and texture depth (y) as dependent variable.

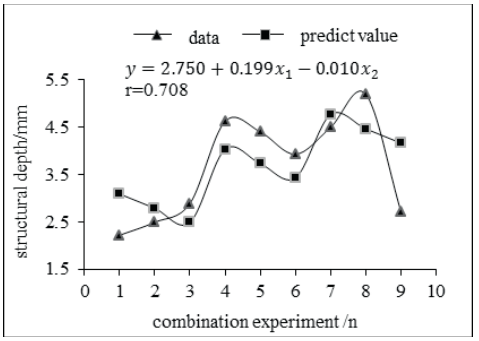

Fig.8 Regression analysis of texture depth of 1cm icy layer

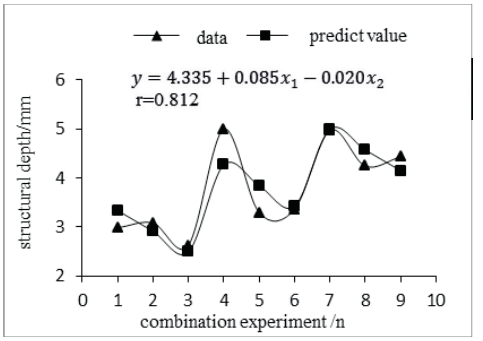

Fig.9 Regression analysis of texture depth of 2cm icy layer

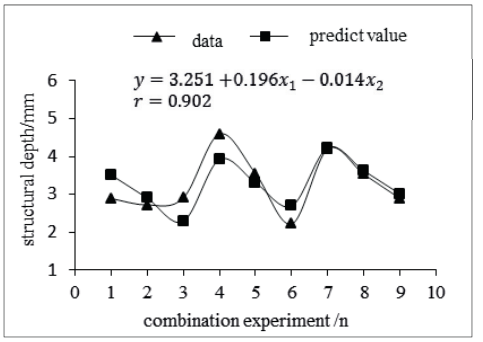

Fig.10 Regression analysis of texture depth of 3cm icy layer

The Figures 8 to Figure10 show that texture depth has positive correlation with particle size of macadam and negative correlation with temperature of macadam. So the texture depth is maximum when using 13.2mm particle size and 60℃ macadam temperature.

5.3.3 Regression analysis summary

According to regression analysis we can get the matching characteristics among the thickness of ice layer, particle size of macadam and temperature of macadam. But there are many limits in practical application. If we use large size macadam to achieve large friction force and texture depth, it may lead to a bad ride quality and increase tire wear. 9.5mm size macadam is commonly the biggest size in asphalt surface tack coat, and this standard is also applicable to the hot melting macadam anti-sliding layer. If we use high temperature to get high stability, it may increase energy expenditure and also add the difficulty to keep macadam warm. The higher temperature the macadam has, the more melting water there be. And it also takes more time to freeze again. If we use low temperature macadam to reach large texture depth, it may reduce the strength between macadam and ice layer. According to the above analysis, we recommend to use 9.5mm and 90℃ as the aggregate size and temperature when the thickness of ice layer is 1-3cm.

6. Conclusion

- There are significant interactions among the thickness of ice layer, particle size of macadam and temperature of macadam;
- The BPN and texture depth for hot melting macadam anti-sliding layer are maximum and the application performance is best when the thickness of icy layer is 2cm. The strength of anti-sliding layer is small when the thickness of ice layer is too thin, and the friction force is small when the thickness of ice layer is too thick.
- The bigger particle size of macadam is, the bigger BPN and texture depth the hot melting macadam anti-sliding layer have.
- Because the strength of anti-sliding layer does not meet the basic requirements, the 60℃ macadam temperature cannot be used when combined it with 9.5mm and 13.2mm size macadam,.
- There is a great quantity of melting water when using 120℃ macadam temperature, so we suggest the traffic should be controlled until the hot aggregate and icy layer bond again.
- After comprehensive evaluation to the theoretical analysis and economic benefit, 9.5mm aggregate size and 90℃ macadam temperature are recommended when the thickness of ice layer is 1-3cm.

References

[1] Changzheng Jin, & Chen Bai (1996). Discussion on removing snow and ice on roads. Science and Technology of Henan Communication, (5):45-46.

[2] Longxi Cui(2010). The research on asphalt mixture include Salt. Chongqing Jiaotong University.
Ferrara AA,& Haslett R(1976). Prevention of preferential bridge Icing using heat PIPes. *federal highway administration*.

[3] Zuquan Tang, Zhuoqiu Li, Zuofu Hou, & Dongliang Xu(2002). The power analysis of De-icing by electrically conductive concrete. Journal of Chongqing Jianzhu University, 03:101-105+116.

[4] Feng Wang, Xiaojiang Li, Weiwei Han, & Desheng Jia(2012). Study on the application of system of snow melting by magnetic energy heating in highway project. *Journal of High way and Transportation Research and Development*, 09:141-143.

[5] Pros, Cons of Sand on Ice and Snowpack(2001). *University of New Hampshire Technology Transfer Center*, Fall(3): 6-7 .

[6] Wilfred A, & Nixon(2001). The use of abrasives in winter maintenance final report of project Tr 434. I*owa Department of Transportation and The Iowa Highway Research Board*, 2001:1-3.

[7] Alex Klein-Paste, & Nirmal K (2010). Comparison between rubber–ice and sand–ice friction and the effect of loose snow contamination. *Tribology International*, 43: 1145-1150.

[8] Rongli Gao (2007). The use of snow-melting agent abroad.*China Highway*, (1)：61-61.

[9] Naifeng Hong (2000). Deicing salt's corrosion and durability of reinforced concrete. *Architecture Technology*, 02:102-104.

[10] Dan Hong (2010). Study on rough riding surface for anticing. *Chongqing: Chongqing Jiaotong University*.

[11] Yuzhen Zeng, & Zhenghuan Liao (2000). The application of waste tire in road engineering abroad. *Journal of China & Foreign Highway*, 01:40-42.

[12] Glover C, & Davison R (1998). High-cure crumb rubber modified asphalt for dense-graded mixes. *Project Summary Report*.
[13] Chunxiu Zhou， & Yiqiu Tan (2008). The study on the application technology of crumb rubber asphalt pavement. *Journal of High way and Transportation Research and Development*, S1:18-23.

[14] Hongwei Zhang (2009). Research on the antifreezing asphalt mixture by crumb rubber modified. *Chang'an University.*

[15] Jie Kang (2011). The research on anticoagulant mixture of ice. *Chongqing Jiaotong University*.

[16] Fupu Li, & Zhijun Wang (2012). Experiment of road performance of asphalt mixture with automatic long-term snowmelt agent. *Journal of High way and Transportation Research and Development*. 03:7-11+21.

[17] Junbo Jiang (2010). Discussed the factors influencing the slideproof property of pavement. *Science and Technology Innovation Herald*, 04:77.